UltraScale Computing

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Goals/Acquisition Strategy

Vision:

- **To develop innovative computational models, methods, and mechanisms which explore the limits of Non-Traditional Computing**

Goals:

- **Define models of computation for non-traditional approaches**
- **Define potential elemental computational mechanisms**
- **Validate computational mechanisms through experimentation**
- **Model, prototype, and characterize nontraditional computing approaches to:**
  - **Explore the limits of deep sub-micron Silicon-based technology**
  - **Predict the behavior and the limits of new computational modalities**
- **Create a distributed collaboration framework to:**
  - **Integrate a highly multi-disciplinary research community**
  - **Link critical researchers and scarce resources (eg. biology labs)**

Acquisition Strategy:

- **Yearly Broad Agency Announcements (BAAs)**
  - **Industry/University teams**
  - **University grants and contracts**
  - **Industrial contracts & agreements**
- **Coordinated programs with other ARPA (DSO, ETO, ISO) and other agencies (NSA, NSF, ARO, ONR)**
- **Final BAA during FY98 solicits innovative applications to DoD problems**

The objective of the Ultrascale Computing program is the development of advanced computing technologies which offer spectacular performance/cost/size/power/complexity improvements beyond the thresholds of traditional techniques, materials and processes.

The approach is to experiment with a framework of clever new models of computation and novel physical mechanisms to demonstrate their potential payoff and to examine present and future computing technologies through modeling and simulation.

Technical Challenges and Approaches

	Challenges	Approaches
New Models of Computation	• 10^4 - 10^5 Processors	Fixed-array, adaptable software
	• 10^6 - 10^8 Processors	No fixed HW; No naming convention; emergent behavior
	• 2^n Processors	Quantum mechanical computing
	• Quantify the limits of these technologies	Hierarchical models based on ab initio calculations
New Physical Mechanisms	• Density > 10^{21}Bits/cm^3	DNA/Molecular
	• Ultra-Low cost	Bioengineering of one-celled organisms
	• Interface bio-networks with Silicon circuits	Cultured neuronal material on Silicon
	• Estimate the limits of new technologies	Computational methods/simulations to model, prototype, and characterize non-traditional mechanisms

Two principal areas of focus for the program are:

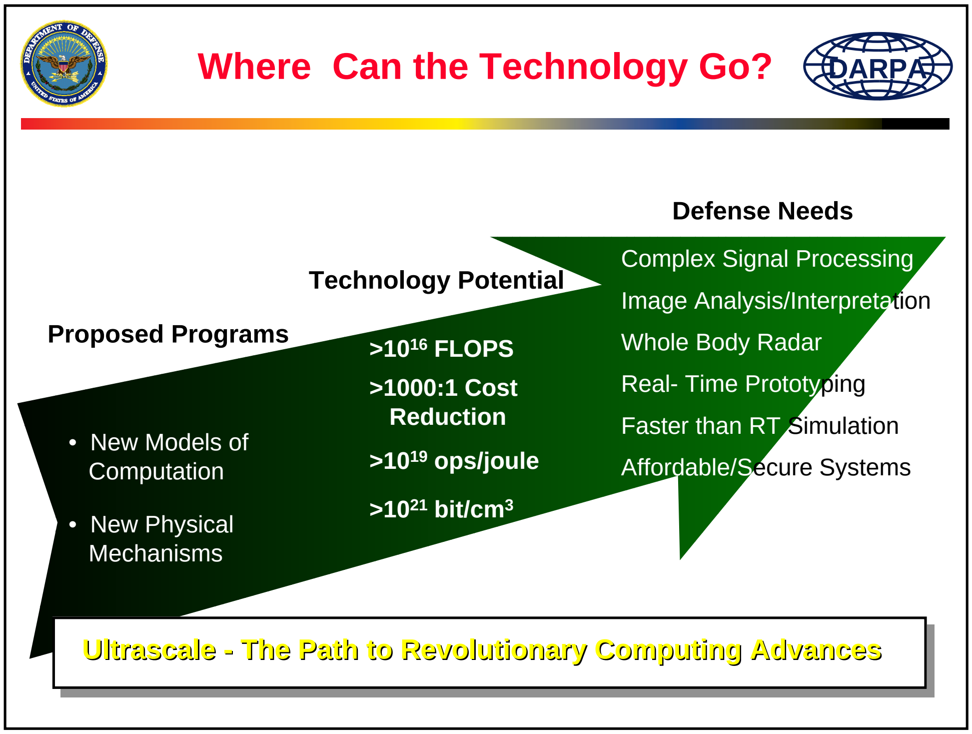
- **NEW MODELS OF COMPUTATION** will develop new approaches to dealing with extremely large numbers of processing elements. At the low end of that scale, novel architectures will be sought which have promise of efficiently using tens of thousands or even hundreds of thousands of processors while avoiding the execution logic overhead of today's parallel schemes. At the millions of processor regime, languages, protocols and algorithms will be developed to interact with independent, unnamed and in some aspects unknown processors to elicit the 'emergent behavior' we desire. At the upper end of complexity the use of superimposed and entangled quantum states of matter will be explored to examine the feasibility of 'quantum computing' as a means of dealing with exponentially large problems currently beyond the scope of deterministic computers.
- **NEW PHYSICAL MECHANISMS** will explore the biological domain at three distinct levels: Molecular level-the DNA molecule will be examined as a data storage and processing opportunity; One celled organisms-these will be exploited as the bioengineers have done by manipulating gene structure to elicit desired behavior such as pattern replication, novel manufacturing and direct computing; Multicellular level-neuronal material will be cultured to produce patterned neural networks in vitro or (in silico) to directly interact with signals from electronic circuits via direct interface.

Program Plan

	FY96	FY97	FY98	FY99	FY00
New Models of Computation					
Fixed Array, Adaptable Software Develop and assess the viability of the Continuum Computer Architecture (CCA) to achieve ultrascale computing performance of 100 teraflops	• Develop languages and protocols for CCA	• Validate CCA with simulation and formal methods	• Evaluate physical resource requirements and feasibility of implementation with CMOS technology in 5-10 years	• Evaluate CCA concept with scalable subset of hardware	• Demonstrate 100 teraflop technology from CCA
Amorphous Computing Create the technological, algorithmic, and architectural foundations for exploiting programmable materials	• Develop instruction set design, communication protocols, and algorithms for amorphous computing (AC)	• Develop local geometry, topology, and communication models	• Design and simulate amorphous array concepts with >1000 elements	• Demonstrate amorphous array concepts	• Demonstrate amorphous array concepts with >1,000,000 elements
Quantum Computing Develop the foundations for a quantum computing engine that will be capable of performing calculations infeasible on today's computers	• Develop simulators and models of quantum computing systems and communication channels	• Develop advanced quantum computer architecture for a general purpose computer	• Model and characterize the limitations of interfacing quantum computers to silicon electronics	• Determine feasibility of porting military problems to quantum mechanical computing systems	• Determine degree to which a physical realization of quantum computing is possible
New Physical Mechanisms					
DNA Computation Develop the technologies for performing computations at the molecular level and strategies for solution to military relevant NP-hard problems	• Develop algorithms for molecular and biological computation	• Simulate limits of molecular and biological computations	• Evaluate manufacturability of molecular computation	• Develop and test chemical protocols for performing >50 sequential operations on a combinatorial set of molecules	• Determine feasibility of porting defense applications to biomolecular computation
Cellular Engineering Exploit bio-engineering of one-celled organisms to achieve computation and low cost manufacture of computational elements	• Evaluate candidates for cellular engineering through fundamental models and simulations	• Establish experimental techniques for engineering biological computing	• Establish the feasibility of implementing a state machine in a biological system	• Establish feasibility of parallel, coupled biological state machines	• Demonstrate low cost manufacturing of computational elements using engineered cells
Cultural Neural Networks Develop in vitro growth of neuronal materials to synthesize cultured neural networks which interface directly with electronic circuits		• Evaluate surface patterning techniques for culturing neural components on silicon	• Demonstrate 2-cell neural circuit	• Transfer data to/from silicon/neural interfaces	• Demonstrate computation between 2-cell neural network and silicon logic

Initial efforts will:

- Explore new models of computation to evaluate concepts which promise vastly superior levels of performance, completely new approaches to dealing with complexity and problem solving.
- Experimental characterization of new physical implementations of computing systems will be performed to verify that current notions of limitations on cost, density and computational efficiency can be drastically altered.
- Computational models and evaluation techniques will be developed which leverage existing technology modeling capabilities in order to fully explore the opportunity space offered by new models of computation and new physical mechanisms through "what if" scenarios to predict viability and performance.



Military applications are insatiable users of computing capabilities - - every improvement drives newer, higher military requirements.

We need to begin to explore now the foundations for new technologies which will take us into the Third Millennium and satisfy military computing needs for:

- complex signal processing capabilities for SONAR and Synthetic Aperture Radar;
- precise prediction of the radar cross section of complete vehicles from all aspect angles over broad frequency ranges;
- computationally prototyping complex new systems to accelerate the acquisition process and reduce program risk;
- providing affordable means for robust, homeostatic information systems which are survivable, resistant to internal faults and defeat external attempts at disruption;
- providing faster than real time simulations involving millions of interacting elements with “real life” image quality to facilitate the policy and strategy analysis as well as embedded training necessary to prosecute “continuous war.”